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A STUDY OF THE PLEIADES CLUSTER

BY ROBERT TRUMPLER

The comprehensive study of the *Pleiades* cluster now in progress may be divided into four distinct parts:

1. A series of accurate measures of the relative positions of the stars.
2. A determination of the proper-motions of these stars by means of all observations now available.
3. A determination of the magnitude and spectral type or color-index of the stars.
4. A statistical investigation of the constitution of this interesting cluster, based on the results of the first three parts.

The addition of a fifth part studying the radial velocities would be desirable. So far radial velocity measures have been made only for a few of the brightest *Pleiades* stars, and their spectral type (B5-B8) is not favorable for obtaining accurate results. With the aid of one of the new large reflectors it should be possible to obtain radial velocity determinations for some of the fainter group members (6-9th fotogr. magn.), the spectra (A0-F0) of which are better suited for such measures.

I. MEASURES

The program for the new measures of the relative positions of the stars was chosen so as to serve best the purpose of determining proper-motions suitable for statistical investigations. The apparent diameter of the *Pleiades* cluster was determined from star counts on the B. D. charts. It was found that the cluster extends as far as 3° from the center, and this result has been confirmed by the study of the proper-motions.¹ Most of the earlier observers had confined their measures to stars within less than 1° from the center. As the work of measuring the fainter stars in such a large field would have been too great, the star list was divided into two parts: The first part consists of the 243 stars of the *Astronomische Gesellschaft Catalog* within a circle of 3° around the center of the cluster; it is complete for all stars (198) equal to the magnitude 9.0

¹Publ. of the Amer. Astr. Soc., 3, 333.

of the B.D. or brighter. The second part contains 964 stars within a square of 2° side having *Alcyone* at the center, and is complete for all stars (914) brighter than the photographic magnitude 14.5 (Hertzsprung's scale²). Since the two lists have some stars in common, and including some stars measured for technical reasons outside the limits of both lists, the total number of stars measured is 1180.

For the measures made at the Allegheny Observatory by the photographic method, plates taken with three instruments of different focal lengths were used:

The 3-inch Doublet Camera of the Allegheny Observatory ($f=1630\text{mm}$): 7 plates.

The Astrographic Refractor of the Zurich Observatory ($f=3435\text{mm}$): 1 plate, secured and kindly lent by Professor Wolfer.

The 30-inch Photographic Refractor (Thaw Telescope) of the Allegheny Observatory ($f=14130\text{mm}$): 15 plates.

2. PROPER-MOTIONS

The determination of the proper-motions is based on the measures just mentioned together with all previous accurate observations. The idea is to form a catalog of the mean positions and proper-motions of the stars giving the best results at present attainable, which should represent and replace the numerous measures scattered thruout astronomical literature. Any work on proper-motions will, of course, be superseded in time; such a collective catalog should, however, greatly facilitate any future work, as it can easily be combined with additional observations.

The observations used for the determination of the proper-motions are taken from 129 catalogs of meridian observations made between 1745 and 1915 and from 40 series of measures made with the heliometer, micrometer, or by photography. The number of catalog positions is about 12,000 in each coördinate, and these represent the results of about 25,000 individual observations in each coördinate.

To obtain the best results a new uniform reduction of the previous measures is necessary, as well as a determination of their accuracy, which will permit us to attribute to each measure the proper weight. The positions and proper-motions of the new catalog are based on the system of Boss' *Preliminary General Catalogue*. The most important items of the new reductions are to correct the

²A. N. 199, 251.

meridian observations for errors depending on the magnitude of the stars and to determine the correct scale value and position-angle orientation for the measures made with the heliometer or by photography. The severe test to which all measures were subjected gives a great amount of information about the systematic errors and the accuracy of the different methods for measuring the relative positions of stars.

From the corrected observations the mean position for the epoch 1900.0 and the proper-motion are derived by least-squares solutions. For the brighter stars the observations are very numerous; for the fainter stars the proper-motions are principally based on the following series of observations:

The micrometric measures of 63 faint stars made by A. Hall with the 26-inch refractor of the Naval Observatory (1886-1888), repeated by E. E. Barnard with the 40-inch Yerkes telescope (1903-1906 and 1917-1919). The photographic measures of 263 stars by F. J. M. Stratton (1892 and 1906).

The Astrographic Catalogue zone of the Paris Observatory (1892-1899).

The Astrographic Catalogue zone of the Oxford Observatory (1894-1909).

Besides these published observations the following early photographs of the *Pleiades* were measured and reduced by the writer:

Three plates taken with the Astrographic telescope of the Oxford Observatory (1891-1893) kindly lent by Professor Turner (of which one is an exposure of 2^h) and one plate taken with the 36-inch Lick telescope (1890) covering a part of the central field.

For the brighter stars (3-8 magn.) of the central region the probable error of the proper motion is approximately $\pm 0''.1$ per century, which is about 2 per cent of the proper-motion of the group. The catalog therefore will be able to predict the relative positions of these stars for the next 50-60 years within a probable error of less than $\pm 0''.1$. With decreasing brightness of the stars the accuracy of the proper-motions of course diminishes, but even for the fainter stars (12-14.5 magn.) the average probable error of the proper-motion does not exceed $0''.5$ per century.

3. MAGNITUDE AND SPECTRAL TYPE

For a cluster like the *Pleiades* all group stars are, as far as their magnitudes are concerned, practically at the same distance from

us, and the observed magnitudes give us direct information about their relative luminosity. To obtain the absolute magnitude (the brightness of a star as seen from the unit distance) we have only to add a constant, depending on the distance of the cluster, to the observed magnitudes.

The new *Henry Draper Catalogue* gives the spectral types, determined at the Harvard Observatory, for most stars of the first part of our program (the brighter stars within the field of 3° radius), and the photographic magnitudes of all stars outside the central field were determined with the aid of the 3-inch Doublet Camera and the 30-inch refractor of the Allegheny Observatory. For the central field Dr. Shapley of the Mount Wilson Observatory has taken over the task to determine the magnitudes and colors of the stars according to the method used in his "Studies Based on the Colors and Magnitudes in Stellar Clusters."

4. STATISTICAL INVESTIGATION

As the work on the proper-motions is not yet finished, it is for the moment only possible to indicate the lines which this investigation has to follow together with a few preliminary results.

Our star list still contains a number of stars which are projected on this part of the celestial sphere only from our point of view, but are situated either in front of or behind the cluster and have no physical connection with it; we shall call them the background stars. Our first step is to separate the group members from the background stars. For this purpose proper-motion and spectral type may serve as criteria, as the proper-motions of the brighter *Pleiades* stars are found to be very nearly parallel and equal, while the spectral type seems closely related to their luminosity.

Considering for the moment only those stars marked as group members, we may proceed to study their distribution among the different degrees of luminosity as well as their special distribution. Counting the number of stars for each magnitude interval we obtain what we may call the *luminosity law* of the cluster. The following Table 1 gives the preliminary results for this law separately for the central circle of 1° radius and for the whole cluster; for the fainter stars the photographic magnitudes are estimates based on Hertzsprung's scale.

TABLE 1
LUMINOSITY LAW OF THE PLEIADES

Photogr. magn.	Within 1° from Centre Group stars	Backgr. stars	Per cent gr. st.	Whole Cluster Group stars	Average spectr. t.
2.5-3.5	1	0	100	1	B5
3.5-4.5	5	0	100	5	B6
4.5-5.5	2	0	100	2	B7
5.5-6.5	7	0	100	8	B9
6.5-7.5	10	3	77	18	A0
7.5-8.5	16	1	94	24	A2
8.5-9.5	13	5	72	30	F2
9.5-10.5	13	8	62		(F9)
10.5-11.5	23	30	43		
11.5-12.5	37	55	40		
12.5-13.5	29	103	22		
13.5-14.5	38	289	12		
> 14.5	7	44	14		
Total.	201	538	27		

Tho the figures may undergo some small changes when the definitive results are available, the table proves beyond doubt that the members of the *Pleiades* group are spread over a large range of luminosity, exceeding twelve magnitudes; i. e., the brightest member is over 50,000 times more luminous than the faintest group stars observed. The number of group stars for each magnitude interval increases very gradually as the stars become less luminous and may perhaps reach a maximum near the limit of our table. The progress of these numbers indicates that we should expect group members even fainter than our magnitude limit. The fourth column of our table tells what per cent of all stars of any magnitude interval are group members. While nearly all the brighter stars of the central region are members, only a small percentage of the fainter stars belongs to the group; this explains why the cluster is conspicuous only by the brighter stars. It may be interesting to note that this preliminary luminosity law of the central region of the *Pleiades* differs considerably from that of the fixed stars in the average as established by Kapteyn³ and Schouten⁴ in so far as the *Pleiades* stars seem to have a larger range of luminosities. The same result has been found for the cluster *h Persei* by means of star counts.⁵

³Gröningen Publ., Vol. 11.

⁴The Statistical Laws of Stellar Astronomy. (Diss.)

⁵R. Trumpler, *Comparison and Classification of Star-Clusters*. Publ. of the Allegheny Observatory (in press).

The last column of Table 1 gives evidence of the remarkable relation between the spectral type and luminosity of the *Pleiades* stars.

Counting the group members in successive concentric rings around the center of the *Pleiades* and dividing the numbers by the surface of the rings we obtain the star densities (star numbers per square degree) at different distances from the center, or the *density law*. Table 2 contains the preliminary results for this relation for the stars brighter than the magnitude 9.0 of the B.D.

Distance from Centre	Group Stars	Star Density
0 - 0°.5	28	35.9
0.5-1 .0	22	9.3
1.0-1 .5	10	2.5
1.5-2 .0	10	1.8
2.0-2 .5	6	0.8
2.5-3 .0	8	0.9
> 3.0	(2)	

We have a very rapid decrease in the star density between 0°.5 and 1° from the center and that is the place where most observers have estimated the limit of the cluster. This concentrated part, however, is surrounded by a region which on account of the small density of the group stars is not conspicuous but which by its large surface yet contains a considerable part of the group members.

As to the proper-motions we are most interested in the internal motions, i. e., the movements of the individual stars with respect to the center of gravity of the whole cluster. The statement made above that the proper-motions of the *Pleiades* stars are very nearly parallel and equal is equivalent to saying that the internal motions are small as compared with the motion of the group, which is 5".3 per century. The small differences between the observed proper-motions of the group stars are due to two causes: to errors of observation and to internal motions. It is for this reason that the accuracy of the observations has to be determined very carefully, so that we may evaluate how much of the observed differences comes from the first source and what is the average amount of the internal motions. The internal motions need not be of the same size for all classes of stars; they may vary with their luminosity or their distance from the center of the cluster.

The fact that the observed radial velocities (Adams, Hartmann) of the six brightest stars differ considerably while their proper-

motions are so nearly alike is rather puzzling. If the radial velocity observations are correct it can only be explained by the assumption of a very great distance of the *Pleiades* ($\pi < 0''.002$).

It will further be of interest to test, whether the internal motions have a tendency to give the group a rotational movement or to produce a contraction in the size of the group. The latter effect may be expected from the radial velocity observations which indicate that in the mean the group is receding from the solar system at a speed of 10 km a second. The amount of this contraction, or what is equivalent to it, the converging point of the proper-motions of the group stars will give some information about the distance of the *Pleiades*, as it is proportional to the parallax. If we assume the parallax of the *Pleiades* as $0''.01$, two stars distant 1° should seem to approach each other by $0''.037$ per century. Altho this is extremely small it should be possible to detect an effect of this size with the aid of the group stars situated at distances between 1° and 3° from the center.

In Table 3 the different methods giving information about the parallax of the *Pleiades* are put together. The result so far obtained show rather a large range.

TABLE 3
THE PARALLAX OF THE PLEIADES

1. Direct measure of relative parallax.	$\pi = -0''.002 \pm 0''.011$ (Yale) ⁶
2. Converging point of proper-motions.	
3. Average intern. motion in p. m. and rad. vel. $\pi < 0''.002$	
4. Group motion (supposing Pl. at rest).	$\pi = +0''.014$ (Hertzsprung)
(supp. it par. to plane of milky way).	$\pi = +0.018$ (Kapteyn)
	$+0.024$ (Plummer)
5. Orbital motion of binaries ⁷	
6. Mean abs. magn. of B-type stars (3-7 magn.). $\pi = +0.006$ (Hertzsprung)	
Mean abs. magn. of st. 5.5-9.5 m. from sp. type.	$\pi = +0.005$ (W. H. Pickering)
7. Luminosity law.	$\pi = +0.036$ (Schouten)

While the first three methods are based on geometrical considerations only, the others require some more or less plausible assumptions.

Incidentally the proper-motions, magnitudes and colors obtained for the background stars will be useful for statistical investigations on the stellar system in the average.

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⁶Derived from the results in *Yale Trans.* **2**, 215, by using the measures of the 3 group stars E8, E43, E62, and the one comparison star E36 with small p. m., the parallax of which was assumed according to van Rhijn's table (*Ap. Jour.*, **43**, 41).

⁷There are three close double stars sharing the proper motion of the *Pleiades* group, which seem to show orbital motion: $\beta 536$, $\beta 537$, $\beta 1105$.